Natasha Latouf - Graduate Research Plan Statement

The search for an Earth-mass analog has been a driving force behind exoplanet science. The search to find habitability, the possibility of water and life, has entranced scientists for decades and the public for millenia. However, one of the biggest roadblocks to this goal is the precision with which we can measure radial velocities. Radial velocities (RVs) are important for detecting and characterizing exoplanets. By using the Doppler Shifts of the observed spectrum of a star, we can use the time-dependent RVs of the star to infer the existence of a planet. In my previous work, we quantified the effects of the atmosphere, hereafter called tellurics, on ground-based radial velocity measurements. Our project was initiated as part of NASA's Probe-class mission concept study EarthFinder (Plavchan et al. 2018). The EarthFinder study looked holistically at how much we would benefit bypassing the Earth's atmosphere altogether with space observation, examining technology challenges, ancillary science, and stellar activity. However, regardless of whether or not we will be able to observe from space, examining the impact that spectral resolution has on our measurement accuracy from the ground would provide valuable insight into how to improve our results now. Higher spectral resolution may give us the ability to mitigate almost all telluric influence and stellar activity, allowing for more precise measurements and much higher accuracy in exoplanet detection. However, higher spectral resolution comes at several costs. Either astronomers would need to build multiple costly telescopes with larger diameters, or the exposure times during observing will need to be extended significantly, when astronomers already fight for minimal telescope time. ***I propose to simulate a extreme precision radial velocity spectroscopic observations of Earth-mass exoplanets using the Keck telescopes as a benchamrk reference to determine the optimal spectral resolution for the mitigation of the deleterious systematic effects introduced by tellurics and stellar activity, while maintaining cost efficiency.***

Intellectual Merit

Exoplanet science is booming, with 4,277 confirmed planets as of September 16, 2020 (NASA Exoplanet Archive). Exoplanet confirmations happen almost daily, and with each RV observation there are the same problems: either the tellurics cannot be mitigated, the stellar activity of host stars from star spots and plages is too high, or both. Both problems can be fixed with higher resolution, but securing time on such an advanced instrument can be very difficult. My goal is to determine a feasibly cost-effective spectral resolution that can be reached by ground-based telescopes by simulating the conditions of any given observational night over the course of a multi-year survey. This project builds on my experience in simulation of radial velocities, doppler shifts, telluric line profiles, and mitigation of tellurics. My existing code can be used and adapted to introduce the effects of varying spectral resolution.

1. First, I will adopt the sun-like stellar spectra generated by ATLAS9 (Kurucz 2005) of a realistic multi-year survey duration with each night separated into 230 chunks based on spectral weighting over the wavelength range of 0.4-2.5 microns. I will adjust the spectra to account for Earth's motion over the course of the year and then pass it through Earth's atmosphere. I also use the atmospheric absorption spectra generated by the TAPAS et. al (2018) website with simulated airmass, precipitable water vapor, as well as daily and seasonal variations. This will provide a known stellar source and telluric line profile for the simulation.
2. I will then multiply the TAPAS telluric line profile and the stellar spectra together to simulate realistic observed data. Previously the multiplied profiles were broadened by the spectrograph response function to a resolution of 120,000; for the purposes of this project, they will be broadened by varying resolutions to find the optimal feasible resolution.
3. I will use two different approaches for RV extraction, the cross correlation function (CCF) and forward modeling. For each method, we use either a perfectly known telluric line profile, an imperfectly known telluric line profile, which purposefully introduces controlled error, or ignore the tellurics altogether in the RV extraction.
    a. In the CCF method, I will mitigate tellurics by dividing the telluric spectrum out of the convolved spectrum. In forward modeling, I will include the telluric model's five molecular species as part of the model, so that they can be adjusted for.

   b. For the imperfectly known telluric line profile, we use a scaled telluric line profile that is from a different observing site than where the spectra is 'collected'. For the purposes of this experiment, we still use a simulated telluric line profile, just from a different observing site.

4. We will use the scatter (rms) of the recovered RVs relative to the injected RVs from all 365 nights within each of the 230 wavelength chunks for each method to estimate typical RV error caused by tellurics for the simulated star. By extracting the RV's from the original, uncontaminated spectra, and the contaminated spectra, we can quantify the RV errors introduced by Earth's atmosphere as a function of spectral resolution.
5. The experiment will be repeated at varying spectral resolutions to compare error across different spectral resolutions. It will also be repeated for various stars, such as an M-Dwarf instead of a Sun-like star. This will provide a wealth of information regarding error as a function of spectral resolution and observed star size. This information will be used to perform a critical analysis of the optimal spectral resolution possible given current technological constraints and cost.

While this initial portion of the experiment is set to take approximately a year due to the amount of testing required for two separate targets, it will only cover the telluric mitigation and error discussed above. In the remaining year and a half, the code will be adapted to perform a dissection of error regarding stellar activity, the effectiveness of common mitigation techniques, and the influence that spectral resolution has on mitigating stellar activity. While tellurics may potentially be largely mitigated with higher resolutions, stellar activity presents a more extensive challenge. As has been studied by Dumusque et al. (2018) and Cegla et al. (2019), stellar activity is the main limitation to Earth-mass analog detections when using the Doppler RV method. Thus, studying the influence of this activity and how much more effective mitigation techniques become at higher resolutions provides valuable information towards the understanding of the best mitigation technique possible.

Broader Impacts

My work will aid the scientific community in understanding the challenges from tellurics and stellar activity in achieving the ~9cm/s Doppler detection threshold of an Earth-mass planet orbiting in the habitable zone of a Sun-like star, and how spectral resolution may be optimized to mitigate systematic sources of radial velocity error. Revolutionizing the current landscape of Astrophysics is a goal I am fiercely committed to, considering the lack of women and minorities in the field, and the obstacles in play. Studies have shown that the current educational methods of physics directly result in lower rates of retention, especially in women and minorities (Lock et al., 2019). This, combined with a lack of mentorship and departmental aid, results in far more difficulty for women and minorities to be awarded a physics degree. I currently am a co-founder and President of a student-led organization, Spectrum, which aims to provide resources, mentorship, and educational opportunities to women and minorities to increase retention and a stronger connection to physics identity. I plan to continue fostering this organization, building and expanding it, while using my research to inspire young women and minorities to follow science. More specifically, I am spearheading an initiative to bring physics and astronomy to children in my local area. This initiative will focus on making physics accessible and appealing to grade-school students by providing lessons in physics and astronomy, tours of the George Mason observatory, and access to a student panel to ask questions about their research experience. The impact of seeing a scientist and role model you can relate to is significant, and my work will lend itself to providing inspiration to younger scientists and keeping them interested in the field, while illuminating a path forward to pursue physics.

References.

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